NEW VIEWS OF

MR. GEORGE H. DARWIN'S THEORY

OF THE EVOLUTION OF THE

EARTH-MOON SYSTEM,

CONSIDERED AS TO ITS BEARING ON THE QUESTION OF THE DURATION OF

GEOLOGICAL TIME.

BY
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New views of Mr. George H. Darwin's Theory of the Evolution of the Earth-Moon System, considered as to its bearing on the question of the duration of Geological Time. By Samuel Haughton, of Dublin, Ireland.

It has been tacitly assumed, even so far back as the times of Newton and Clairaut, that the earth and planets have passed through a liquid condition (owing to former great heat) before assuming the solid condition, which some of them, at least, now possess.

Laplace, in his nebular hypothesis, also assumes the former existence of this liquid condition, and it is openly asserted by all geologists who believe that the earth consists of a solid crust (more or less thick), reposing upon a fluid or viscous nucleus.

It has been proved by Sir William Thomson, following out the views of the late Mr. Hopkins, that the present condition of the earth, taken as a whole, is such that it must be regarded as being more rigid than glass or steel, possibly more rigid than any terrestrial substance under the surface conditions of pressure.

The following considerations show that it may be fairly doubted whether the earth or any other planet ever existed in a fluid condition.

1. The possibility of the equilibrium of the rings of Saturn, on the supposition that they are either solid or liquid, has been more than doubted, and the most probable hypothesis respecting them is, that they consist of swarms of discrete meteoric stones.

2. It is difficult to understand the low specific gravity of Jupiter and the other outer planets, on the supposition that they are either solid or liquid, for we know of no substance light enough to form them.[1] If the outer planets consist of discrete meteoric

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[1] The force of this argument could not be felt before the revelations of the spectroscope, because at that time there was no proof that the whole universe was composed of the same simple substances, and those very limited in number.

stones moving around a solid or liquid nucleus, the difficulty respecting their specific gravity would disappear.

3. The recent researches connecting the November, the August, and other periodic swarms of shooting stars with comets tend in the direction of showing that comets, in cooling, break up into discrete solid particles (each no doubt having passed through the liquid condition) ; and that probably the solar nebula cooled in like manner into separate fiery tears, which soon solidified by radiation into the cold of space.

4. Mr. Huggins's recent comparisons of the spectroscopic appearances of comets and incandescent portions of meteoric stones, showing the presence in both of hydrocarbon and nitrogen compounds, confirm the conclusions drawn from the identity of the paths of comets and meteoric periodic shooting stars.

5. Mr. H. A. Newton, in a remarkable paper read before the Sheffield Meeting of the British Association (1879), showed the possibility (if not probability) of the asteroids being extinct comets, captured and brought into the solar system by the attraction of some one or other of the outer large planets, and permanently confined in the space between Mars and Jupiter, which is the only prison cell in the solar system large enough to hold permanently such disorderly wanderers.

In the same paper, Professor Newton threw out the idea that some of the satellites of the large planets might also be of cometary origin.

From all these and other considerations, it is therefore allowable to suppose that the earth and moon, when they separated from the solar nebula, did so as a swarm of solid meteoric stones, each of them having the temperature of interstellar space ; i. e., something not much warmer than 460° F. below the freezing point of water.

Mr. George H. Darwin has shown, admirably, how the earth · moon system may have been developed from the time when the earth-moon formed one planet revolving on its axis in a few hours, to the present time, when the earth and moon (in consequence of tidal friction) have pushed each other asunder to a distance of sixty times the radius of the earth.[2]

In his paper on the tidal friction of a planet[3] (supposed viscous and under the influence of bodily tides caused in it by an external

[2] Proceedings of Royal Society, 19th June, 1879.
[3] Phil. Trans., 1881, Part ii, p. 494.

body such as the moon), Mr. Darwin has found a remarkable equation of condition, which may be thus expressed:

$$d(\sqrt{r}) \propto \frac{\Psi dt}{r^6} \qquad (1)$$

where $r =$ distance between centres of earth and moon.
   $t =$ time elapsed from a fixed epoch.

$$\Psi = \frac{p(n-\Omega)}{1+p^2 (n-\Omega)^2} \qquad (2)$$

$n =$ angular velocity of earth's rotation.
$\Omega =$ angular velocity of moon's orbital revolution.
$p =$ quantity varying inversely as the viscosity of the planet.

The extreme interest of equation (1) consists in the appearance of the inverse sixth power of the distance.

As the function Ψ varies very slowly, we find by integration, for any portion of time during which Ψ may be regarded as constant

$$t = A r^{\frac{13}{2}} + B, \qquad (3)$$

a most unexpected and remarkable result.

Upon reading Mr. Darwin's papers, my mind turned to a problem with which I was familiar, viz.: the retardation of the earth's rotation produced by the lunisolar tide exerted upon the ocean supposed collected in an equatorial canal, the moon and sun having no declination, and I readily found an equation to express the evolution of the earth-moon system, on the foregoing hypothesis as to friction.

This equation is the following:

$$d(\sqrt{r}) \propto \frac{f\Phi dt}{r^6} \qquad (4)$$

where

$$\Phi = \frac{V_0 (n-\Omega)}{\left\{ 4V_0^2 (n-\Omega)^2 - k^2 \right\} \sqrt{4(n-\Omega)^2 + f^2}} \qquad (5)$$

$f =$ coëfficient of friction supposed proportional to relative velocity.
k varies inversely as r^3.
$V_0 =$ velocity at earth's equator.

This leads, as in Mr. Darwin's hypothesis of viscous earth, to the integral

$$t = A' r^{\frac{13}{2}} + B' \qquad (6)$$

The form of the functions Ψ and Φ is similar, as both ascend by odd powers of $(n-\Omega)$ and vanish when $n=\Omega$, that is to say, at the beginning and end of the evolution by friction of the earth-moon system.

It is quite clear, therefore, that the remarkable expression (1) found by Mr. Darwin, is not peculiar to his special hypothesis of a viscous earth, but can be deduced equally well from the totally distinct hypothesis of an absolutely rigid earth retarded by the tidal action of a liquid ocean.

I was led by this result to consider the case of the earth-moon separating (as I believe they did) from the central solar mass, in the form of a swarm of discrete masses of meteoric iron and stone, each one having the temperature of the cold of interstellar space, or not much above it. Translating this conception into mathematical language, I find that the equation of continuity belonging to the hydrodynamical theory applies equally well to the meteoric theory, viz. :

$$vy = v'y' \qquad\qquad (7)$$

where v, v' are the velocities at any two points, and y, y' are the depths of the ocean or meteoric swarm at the same points.

The depth of the swarm or ocean, without jostling or friction will be least under the moon, and greatest at right angles to the moon, and the velocities will be inversely. Hence the chances of jostling among the meteorites, when disturbed by the moon's tidal action will be proportional to the velocity, being greatest where the velocity is greatest and the area of passage least, and *vice versa*.

This consideration reduces the meteoric problem to that of the hydrodynamical problem, with a friction proportional to the velocity, and gives equations, in all respects similar to those derived by Mr. Darwin, from the hypothesis of a viscous earth.

On the meteoric hypothesis, if the jostling of the stones be slow they may cool almost as fast as they are heated and the result will be a cool earth and almost indefinite time at the disposal of geologists.